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MULTI-CHAMBER PACING SYSTEM

Technical field

The present invention relates to a multi-chamber pacing system comprising pulse generator means for successively delivering pacing pulses to chambers of a patient's heart, and evoked response detectors having blanking intervals following the delivery of pacing pulses and including sensing elements for sensing IEGM signals from each of said heart chambers and an integrating means adapted to integrate said IEGM signal within evoked response detection time windows after delivery of pacing pulses for detecting evoked response, said evoked response detection time window for a heart chamber containing at least one blanking interval resulting from delivery of a pacing pulse to another chamber, and each of said sensed IEGM signals having a generally known morphology.

In the following the expression chambers of the heart denotes right and left atria as well as right and left ventricles of the heart.

Background

US 6,148,234 disclose a dual site pacing system, either bi-ventricular or bi-atrial, wherein signals are sensed during the refractory period following delivery of stimulation pulses. Pacing pulses are delivered substantially concurrently to both the heart chambers, although it is mentioned that for patients with an intra-atrial block the left atrium may be stimulated up to 90 msec later than the right atrium. If capture is achieved in both chambers no intrinsic depolarisation signals can be sensed during the following refractory period. If, however, the threshold of either heart chamber has risen above the level of the delivered pulses, that chamber will not be captured and will not have a refractory period following that delivery of the pulses. In this case, for patient's having a conduction delay from one chamber to the other, the excitation signal from the other chamber will be sensed in the non-captured chamber during the refractory period. Such sensing during the pacemaker refractory period is considered to be the result of loss of capture.

If two heart chambers are stimulated at somewhat different times, one of the chambers will be blanked when the other one is stimulated. Most pacing systems are constructed such that all signal channels are blanked when a stimulation

pulse is sent. There will consequently be an interruption in sensed IEGM signals and corresponding evoked response signals obtained by integration of the IEGM signals. This occurs in all dual or multi chamber pacing systems, e.g. at both bi-ventricular and bi-atrial pacing. If sensed signals are integrated in an evoked response detection time interval from e.g. 4 msec to 50 msec after stimulation to determine evoked response, and if a stimulation of the other chamber takes place at 10 msec after the first stimulation there will be an interruption of the signal in the above mentioned detection time interval.

The purpose of the present invention is to propose an improved technique for detecting evoked response in a reliable way at multi-chamber pacing.

Disclosure of the invention

This purpose is obtained by a pacing system of the kind defined in the introductory portion and having the characterizing feature of claim 1.

Thus, the idea of the present invention is to reconstruct the integral of the IEGM signal sensed in one heart chamber during blanking intervals resulting from stimulation in other chambers. The reconstructed integral will normally differ somewhat from the true integral value without blanking, however, this will result in errors of only minor importance and will not negatively influence the possibility of detecting evoked response on chambers having stimulation blankings. When reconstructing the integral of the signal the knowledge of the general signal morphology is utilized. To be able to reconstruct the integral the second pacing pulse in a pair of consecutive pacing pulses must not be delivered within the blanking interval following the first pacing pulse. The pulse generator means are therefore controlled to deliver the second pacing pulse with a time delay exceeding the length of the blanking interval following the first one of said two consecutive pacing pulses. It should also be noted that with the present invention it is also possible to reconstruct the integral in more than one blanking interval, occurring in an evoked response detection time interval as a result of subsequent stimulations in other chambers of the heart. Such a situation can appear if time delays between the stimulations in different heart chambers are comparatively short.

According to an advantageous embodiment of the pacing system according to the invention the signal reconstructing means is adapted to select among several predetermined ways of reconstructing the IEGM signal in the blanking

interval with the aid of the knowledge of the signal morphology. Thus in this way knowledge about the signal morphology is utilized for selecting the best way of reconstructing the signals in the blanking interval.

If a constant signal level u_0 equal to the mean value of the sensed IEGM signal values at the beginning u_1 and at the end u_2 of the blanking interval is integrated during the blanking interval the result may be somewhat noise sensitive, since it depends only the two samples u_1 and u_2. To reduce this noise sensitivity, according to still another advantageous embodiment of the pacing system according to the invention, filtering means are provided to filter the IEGM signal in a filtration time interval of predetermined length to produce a reconstructed signal for use for detection of evoked response, said filtration time interval containing the blanking interval.

According to still another advantageous embodiment of the pacing system according to the invention with the pacing system comprising an implantable lead having a tip and a ring electrode and the pulse generator means having a case, IEGM signals being measured between the tip electrode and the case and between the ring electrode and the case, respectively, a memory means is provided for storing the IEGM signals, and the integral reconstructing means is adapted to integrate the IEGM signal measured between the tip electrode and the case while using that portion of the stored ring electrode to case IEGM signal which corresponds to the blanking interval in the integrated IEGM signal for the integration within the blanking interval. Even though the ring electrode may be floating in blood and the tip electrode is attached to the myocardium and the tip and ring electrodes have different shapes, the signals will look quite similar. Since the ring electrode is further away from myocardium than the tip, the signal resulting from depolarization of myocardium will arrive at the tip electrode before it arrives at the ring electrode. Thus the ring electrode to case signal will be delayed compared to the tip electrode to case signal. If a tip to case signal channel is blanked during the evoked response detection time window, information about the signal in this blanking period can be found in the ring to case signal after a certain time when none of the two signal channels are blanked.

Brief description of the drawings

To explain the invention in greater detail embodiments of the pacing system according to the invention will be described below with reference to the accompanying drawings on which figure 1 shows a simplified block diagram of an embodiment of the pacing system according to the invention, figures 2 - 5 show schematically IEGM signal portions containing a blanking interval for illustrating different reconstructing techniques suitable for use in the pacing system according to the invention, figure 6 is a flowchart illustrating an example of evoked response signal processing during blanking in the pacing system according to the invention, and figure 7 illustrates still another embodiment of reconstruction in the pacing system according the invention.

Description of preferred embodiments

Figure 1 shows schematically a multi-chamber pacing system with leads 42, 44 , 46 having bipolar electrodes 48, 50, 52 implanted in right atrium and in the ventricles of a patient's heart 54. The pulse generator case is schematically shown at 56.

Inside the pulse generator case there are an evoked response detector 58 with IEGM signal sensing means and integral reconstructing means 60 and memory means 62. These components are preferably realized by a microprocessor.

IEGM signals are sensed and integrated by the evoked response detector 58 in a evoked response detection time window. By the integral reconstructing means 60 the integral is reconstructed in blanking intervals resulting from delivery of pacing pulses in other heart chambers. In the memory means measured complete IEGM signals are stored, such that the reconstructing means 60 can use that portion of the stored signal which corresponds to the blanking interval. A complete IEGM signal can be measured in advance and stored in the memory means 62. IEGM signals can alternatively be measured simultaneously between tip electrode, e.g. the tip electrode 64 in the right ventricle and the case 56, and between said ring electrode 66 in the right ventricle, and the case 56. The measured IEGM signals are stored in the memory means 62. Since the ring to case signal is delayed vis-à-vis the tip to case signal, the integral reconstructing means 60 is adapted to integrate the IEGM signal measured between said tip electrode 64 and said

case 56 while using that portion of the stored ring electrode 66 to case 56 IEGM signal which corresponds to the blanking interval in the integrated IEGM signal.

Figure 2 shows qualitatively the simplified appearance of an intracardiac evoked response signal as a function of time following the delivery of a stimulation pulse 2. A blanking interval 4, resulting from the delivery of a pacing pulse in another heart chamber, is limited by two vertical dashed lines 6,8 in the figure. The blanking time is normally 6-15 msec.

Figure 3 shows in an enlarged scale a portion of the intracardiac evoked response (ER) signal in figure 2. Figure 3 illustrates an example where the ER signal during the blanking interval 4 is mathematically reconstructed by using the instant slope at the starting point 10 of the blanking interval. The reconstructed signal is then used for reconstructing the integral of the signal.

Figure 4 shows an example with the blanking interval 12 positioned around a minimum 14 in the intracardiac ER signal. In this embodiment the signal is reconstructed in the blanking interval by using the instant slopes of the intracardiac ER signal at the beginning 16 and end 18 of the blanking interval 12 for linear extrapolations of the signal forwardly from the beginning 16 of the blanking interval 12 and rearwardbly from the end 18 of the blanking interval respectively. This linear extrapolations meet in an intersection point 20, thus forming a reconstructed signal in the blanking interval 12. The reconstructed signal is then used for reconstructing the integral of the signal.

As another alternative the intracardiac evoked response signal can be reconstructed or replaced during blanking by a constant signal level u_0 , e.g. equal to the mean value of the signal values u_1 and u_2 at the ends of the blanking interval 22, see figure 5.

Instead of linear approximations of the signal within the blanking period as described above the signal can be reconstructed by applying a polynomial of suitable degree to the signal by using a plurality of IEGM signal samples preceding and succeeding the blanking interval.

As appears from figures 2 – 5 the ER signal is smoothly varying with time without any discontinuities, and the general morphology or progress of the signal in the evoked response detection time interval can e.g. be determined in advance by introductory measurements and memorized for the subsequent use, cf. the description of figure 1 above.

Figure 6 is a flow chart illustrating an example of signal processing during blanking in the pacing system according to the invention. It is supposed that the evoked response signal processing occurs in e.g. a microprocessor controlled signal process known in the art. The example relates to normal autocapture signal processing just interrupted during blanking caused by stimulation in the heart chamber opposite to the considered chamber. The process disclosed in figure 6 will replace the process, which would otherwise occur in autocapture signal processing if no blanking had occurred. The input to the flow chart in figure 6 is the intracardiac evoked response signal integrated up to the beginning of the blanking interval or blanking point. The flow chart then illustrates the signal processing up to the end of the blanking interval whereafter the integrated evoked response signal is further processed in the normal, well-known way for evoked response detection.

VBLNK, see 24 in figure 6, denotes ventricular blanking. Cnt in box 26 in figure 6 denotes counter value, and U_{int} denotes integrated ER signal.

In box 28 U_{int} is integrated during VBLNK. The counter value equals the count number of loops, viz.the number of samples during VBLNK.

Box 30 illustrates the addition of the integrated value of estimated mean value of the signal during VBLNK to the integrated ER signal U_{int} up to the beginning of VBLNK.

The resulting evoke response signal $U_{evoked\ response}$, box 32, is then further processed, at 34, for evoked response detection according to well-known technique.

Another way of viewing the procedure illustrated in figure 6 is to see the samples in the ER window as a mathematical vector. By taking the dot product of this vector and the vector whose samples are depicted in figure 7 $U_{evoked\ response}$ is obtained. Given the definition of the product, the value of the integrated linearly interpolated evoked response equals

$$U_{evoked\ response} = \sum_{I=1}^{N} u_i \cdot f_i$$

where u_i are the individual voltage samples in the ER window and f_i the (filter) coefficients depicted in figure 7.

The value of the filter coefficients immediately preceding and immediately succeeding the blanking period is equal to 1 + n/2, where n is the number of samples being blanked.

CLAIMS

1. A multi-chamber pacing system comprising pulse generator means for successively delivering pacing pulses to chambers of a patient's heart, and evoked response detectors having blanking intervals following the delivery of pacing pulses and including sensing elements for sensing IEGM signals from each of said heart chambers and an integrating means adapted to integrate said IEGM signal within evoked response detection time windows after delivery of pacing pulses for detecting evoked response, said evoked response detection time window for a heart chamber containing at least one blanking interval resulting from delivery of a pacing pulse to another chamber and each of said sensed IEGM signal having a generally known morphology, **characterized** in that an integral reconstructing means is provided to reconstruct the time integral of said IEGM signal from one of said heart chambers in the blanking interval following delivery of a pacing pulse to another heart chamber.

2. The pacing system according to claim 1, **characterized** in that said integral reconstructing means is adapted to integrate a constant IEGM signal value derived from the known signal morphology within said blanking interval.

3. The pacing system according to claims 1 or 2, **characterized** in that said integral reconstructing means is adapted to integrate a constant IEGM signal value equal to the mean value of the IEGM signal values at the ends of the blanking interval.

4. The pacing system according to claim 1, **characterized** in that a signal reconstructing means is provided to reconstruct said IEGM signal in the blanking interval, and in that said integral reconstructing means is adapted to integrate said reconstructed IEGM signal within the blanking interval to reconstruct the integral in the blanking interval.

5. The pacing system according to claim 4, **characterized** in that said signal reconstructing means is adapted to select among several predetermined ways of

reconstructing said IEGM signal in the blanking interval with the aid of said knowledge of the signal morphology.

6. The pacing system according to claims 4 or 5, **characterized** in that said signal reconstructing means is adapted to reconstruct said IEGM signal within the blanking interval by using the instant slope of the IEGM signal at the beginning of the blanking interval for linear extrapolation of the IEGM signal in the blanking interval.

7. The pacing system according to claims 4 or 5, said IEGM signal having a minimum within the blanking interval, **characterized** in that said signal reconstructing means is adapted to use the instant slopes of said IEGM signal at the beginning and at the end of the blanking interval for linear extrapolation of said IEGM signal forwardly from the beginning of the blanking interval and rearwardly from the end of the blanking interval respectively, till the intersection point of said linear extrapolations.

8. The pacing system according to claims 4 or 5, **characterized** in that said reconstructing means is adapted to reconstruct said IEGM signal within the blanking interval by using a plurality of IEGM signal values preceding and succeeding said blanking interval according to a polynomial of a predetermined degree.

9. The pacing system according to claims 4 or 5, **characterized** in that filtering means are provided to filter said IEGM signal in a filtration time interval of predetermined length to produce a reconstructed signal for use for detection of evoked response, said filtration time interval containing the blanking interval.

10. The pacing system according to claim 9, **characterized** in that said filtering means comprise a FIR filter having filtering coefficients equal to zero within said blanking interval.

11. The pacing system according to claim 1, **characterized** in that a memory means is provided for storing a complete IEGM signal measured in advance in the

whole evoked response detection time window without any blanking interval, and in that said integral reconstructing means is adapted to use the stored IEGM signal for the integration within the blanking interval.

12. The pacing system according to claim 1, said pacing system comprising at least one implantable lead having a tip and a ring electrode and said pulse generator means having a case, IEGM signals being measured between said tip electrode and said case and between said ring electrode and said case, respectively, **characterized** in that a memory means is provided for storing the IEGM signals, and in that said integral reconstructing means is adapted to integrate the IEGM signal measured between said tip electrode and said case while using that portion of the stored ring electrode to case IEGM signal which corresponds to the blanking interval in the integrated IEGM signal for the integration within the blanking interval.

ABSTRACT

A multi-chamber pacing system comprises pulse generator means for successively delivering pacing pulses to chambers of a patient's heart (54), Evoked response detectors (58) having blanking intervals following the delivery of pacing pulses includes sensing elements for sensing IEGM-signals from each of said heart chambers and an integrating means adapted to integrate said IEGM-signal within evoked response detection time windows after delivery of pacing pulses for detecting evoked response, said evoked response detection time window for a heart chamber containing at least one blanking interval resulting from delivery of a pacing pulse to another chamber and each of said sensed IEGM signals having a generally known morphology. An integral reconstructing means (60) is provided to reconstruct the time integral of the IEGM signal from one of the heart chambers in the blanking interval following delivery of a pacing pulse to another heart chamber.

(Fig.1)

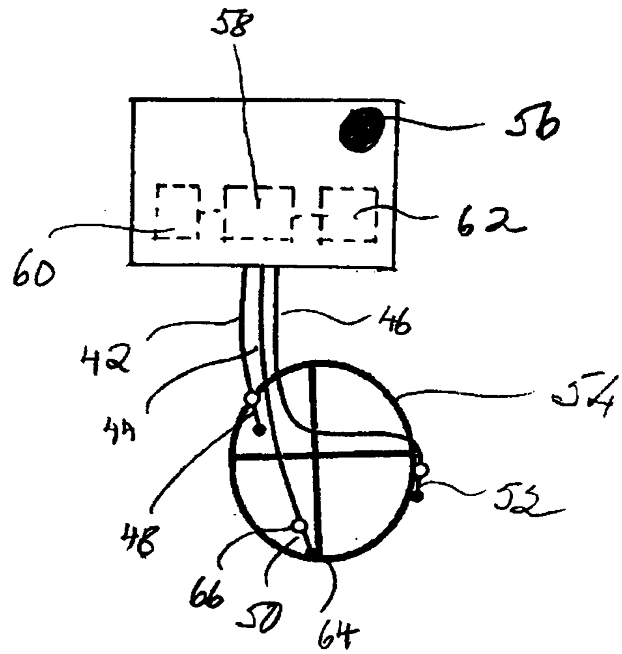
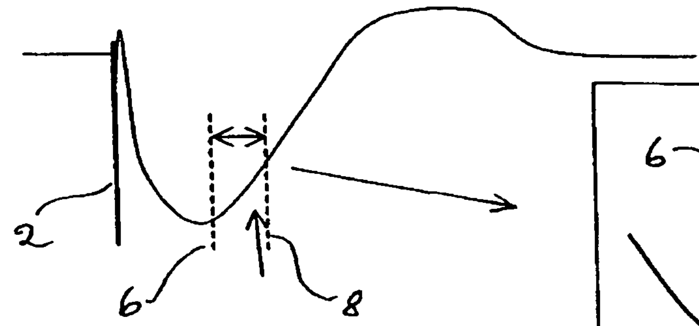


Fig. 1



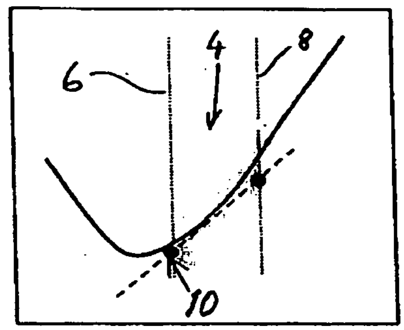


Fig. 2

Fig. 3

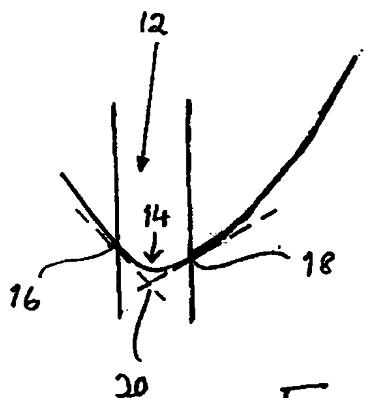


Fig. 4

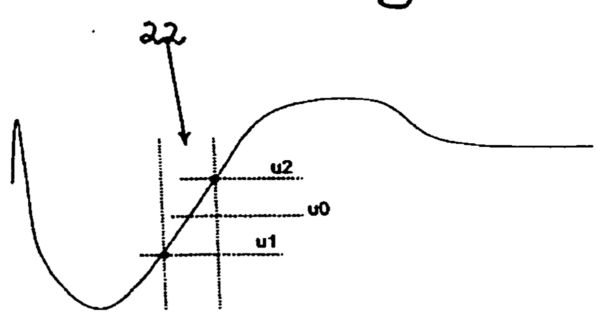


Fig. 5

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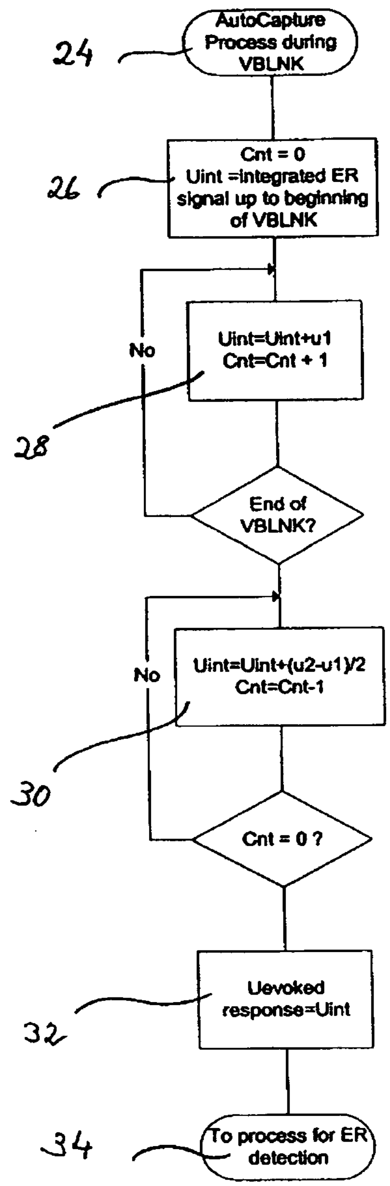

Fig. 6

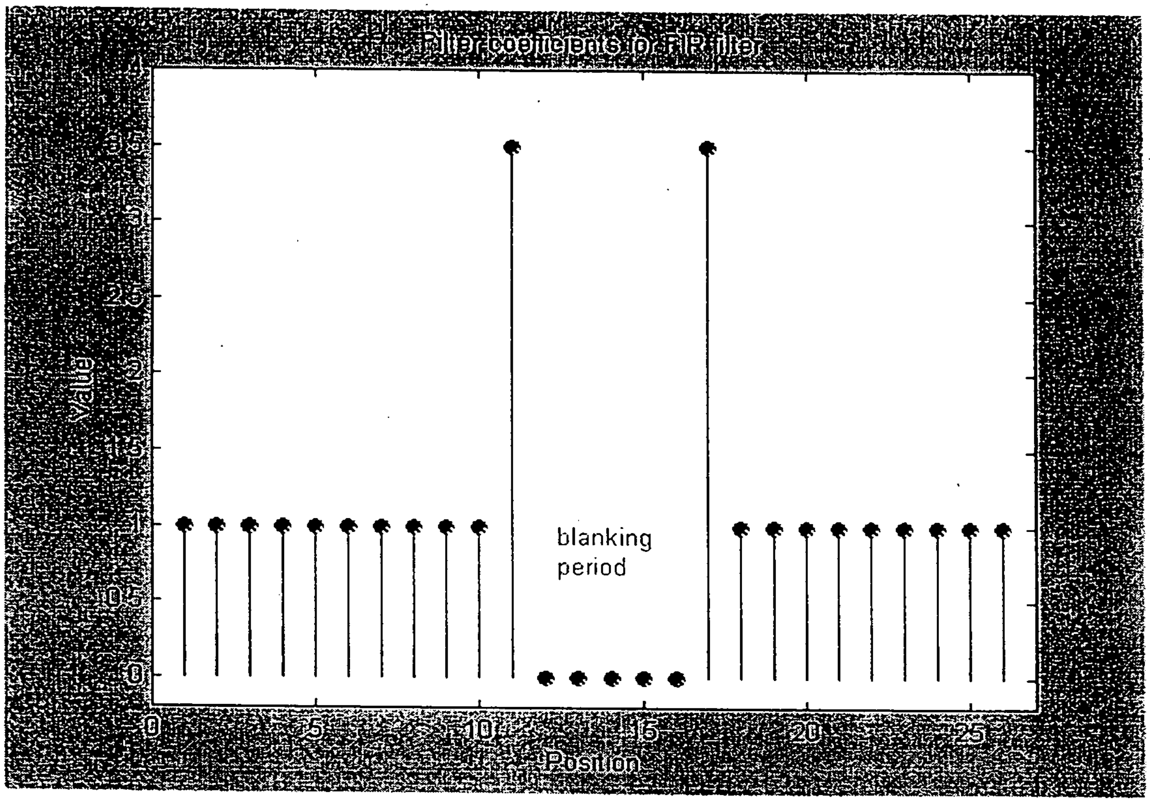
Filter coefficients for FIR filter
Value
4
3.5
3
2.5
2
1.5
1
0.5
0
blanking
period
0
5
10
15
20
25
Position

Fig. 7